APPLICATIONS OF GEOGRAPHIC INFORMATION SYSTEMS IN PUBLIC WORKS

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CHAPTER ONE
INTRODUCTION

1.1 Objectives

Geographic Information Systems are a very useful tool in Civil Engineering and to Public Works in particular. Until recently the use and knowledge of these powerful systems has been reserved to only a small percentage of the engineering community.

There are three objectives to this report. One; to familiarize the non-GIS user with the terms, definitions and structure of these systems. Two; to show some successful applications of these systems in the field of public works. Three; to outline a procedure for custom designing a GIS to a specific use.

1.2 Scope of Report

The original scope of this report was to include a demonstration of a GIS using the GIS lab at the University of Florida and a section of Naval Air Station Jacksonville as the base map. Early in the research for this project it was discovered that to accomplish that would involve more time and resources than were available. The scope of the report was therefor modified.

In Chapter one the basic definitions, terms and structure of a GIS are discussed. This chapter was meant to introduce someone unfamiliar with what a GIS is, to the different components of a system and how a GIS is different from other computer systems.

Chapter two outlines some successful applications of GISs in the field of public works. These are included to enable the GIS new comer to better understand the usefulness of these systems to the engineer in the field of public works.

The third chapter focuses on the design and implementation of a GIS to a specific application. This chapter is intends to show the amount of time and effort involved in

designing and implementing a system. It is also meant to show how a system can be successfully implemented if the design team has support for the rest of the organization.

1.3 Definitions

Geographic Information Systems (GIS) are a unique class of computer software that represent an exciting technology that will have a significant impact on data analysis and information processing during the next decade. GIS links two different technologies, automated mapping and database management systems. Contrary to the vast amount of articles written recently about GIS in news and trade articles, GIS is not a new and unproven technology. The first operational GIS, The Canadian Geographic Information System, began operating in 1962. The first commercially available GIS software became available in the early 1980's. The tremendous exposure and popularity in the last few years is not attributed to the emergence of a brand new technology, but rather to the increased power and decreased cost of computers and the availability of relatively inexpensive digital data (1).

But what is GIS? The use of GIS has grown dramatically from its beginnings in the mid 80's from obscurity to become commonplace in business, universities and governments where they are used for many diverse applications. (2)

Many definitions of a GIS have been developed. One, given from reference 2 is: "An organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced information (2, p. 1-2)." It has also been described as a computer software system that uses geographic references as a means of storing, retrieving, and analyzing data. (1)

Both of these definitions are accurate and widely accepted. They do not however, give the newcomer to GIS a very good feel for what a GIS is and does. A simpler

definition is given as: A compute system capable of holding and using data describing places on the earth's surface.

1.4 SPATIAL OPERATIONS

Many widely used computer systems such as spreadsheets, statistical packages or drafting packages can handle simple geographic or spatial data. Why then are these not thought of as GISs? The answer is that a GIS is only a GIS if it permits the user to do spatial operations on the data. A spreadsheet or database program can give the user a lot of statistics on data and even sort data by geographic location if that is part of the database. A GIS makes connections between the data. In other words, it can tell the user how all the data relates to some grid system, geographically modeled in the real world.

The data linkage aspect of a GIS is key to its ability and usefulness. To further explain this concept, consider the case where you have two different data sets for a given area. One say, showing the type of soil in that tract of land and the other showing the types of vegetation growing there. Without a GIS these two data sets could be mapped or analyzed separately. These two data sets if combined, could only be done in one way. Consider then having 20 sets of data for that tract of land, to include environmentally sensitive areas, runoff areas, owners information, political boundaries and so on, and the different combinations of data would be over a million. Not all of the combinations would provide the user with meaningful information but you would be able to answer many more questions than you could with out the GIS.

A GIS can be further defined by the types of questions it can answer. Location Questions such as: What is at? Where the location can be described as a place name, zip code, or geographic reference such as latitude and longitude.

Condition Questions such as Where is it? This type of question is the converse of the location question. This kind of question gives the answer to what you would find at a given location.

Trends What has changed since? These types of questions might find the differences in an area over a given period of time.

Patterns What spatial patters exist? You could ask this type of question to determine the relationship between two of the items in the database.

Modeling Questions What if types of questions. These types of questions would give answers that relate what effect changing one parameter in the data base will have on the others or one parameter in particular.

So far this discussion of GIS has focussed on what GIS is and what types of questions it can answer. It is also important to state what GIS is **not**. GIS is not simply a computer system for making maps, although it can create maps at different scales, in different projections and with different colors. A GIS is an analysis tool. The major advantage of a GIS is that it allows you to identify the spatial relationships between map features. A GIS does not store a map in any conventional way. Nor does it store a particular image or view of a geographic area. Instead the GIS stores the data from which you can create the desired views drawn to suit a particular purpose. A GIS links spatial data with geographic information about a particular feature on a map. The information is stored as attributes or characteristics of the geographically represented feature. For example a road network might be represented by roadway centerlines. In this case the actual visual representation of the centerlines wouldn't tell the user much information about the roads. To obtain information about the road, such as type, width, age ect, you would need to query the database that stores the attributes of the roadway system. Then the user creates a display showing the particular features he is interested in.

A GIS can use the stored data to compute new information such as length of roads or total area of a particular land use.

A GIS does not hold maps or pictures. It holds a database that the user can query to create maps based on the data. The concept of a database is the central point of a GIS and is what separates it from a drafting or computer mapping program. All GIS packages incorporate the use of a database management system.

If you want a system that does more than make pictures of areas you need to know three pieces of information about every feature on the map. 1) What it is. 2) Where it is. and 3) How it relates spatially to the other features on the map. The database can store a large number of different attributes of a feature.

A GIS gives you the ability to associate information with a feature on a map and to create new relationships that can help the user determine the suitability of various areas for development, evaluate environmental impacts, calculate harvest volumes, identify the best location for a new facility and a number of other useful relationships that help the user make sound decisions concerning the features in his area.

1.5 GIS BASICS

In order for a GIS to work there must first be a digital map database. Some discussion of how the information on the maps is digitized and stored is important to understanding how the database links the geographic information with the attribute information and is able to display useful information for the engineer.

There are two types of information stored in the GIS system. Spatial information, describing the location and shape of geographic features and how they relate spatially to other features. The other type of information is descriptive, telling the user information concerning the type, color, size, age, use or other types of attributes about a particular feature.

Map features themselves can be broken down into three types, point, line and area. A point feature is represented by a location defining an object whose boundary or shape is

too small to be shown as a line or area. It could also represent a point that does not have an area associated with it like an elevation or grid corner. Points are usually depicted with a symbol or label.

Line features are a set of ordered points that when connected represent the linear shape of a map object too narrow to be represented as an area. Or it could represent a line that has no area at all like a contour line or political boundary.

Area features are closed figures whose boundaries enclose a homogeneous area, such as a state, county or body of water.

Spatial relationships on a map are not explicitly pointed out but are part of a map and are represented on it. The person using the map interprets the spatial relationships by seeing how close or how far objects on the map are from one another.

Different symbols and graphics on the map depict descriptive information. For example, different types of roads on a map may be represented by different sizes of lines. Different land uses may be represented by separate colors or by different fill patterns on the map. Certain buildings like schools and hospitals may have their own unique symbol on the map.

1.6 STORING DATA

Maps are made by representing features on the earth's surface in a two dimensional flat appearance as points lines and areas. An x-y (Cartesian) coordinate system is then used to reference the map locations to the real world ground locations. Each point on the map has its own x-y location. Lines on the map are recorded as a series of ordered x-y pairs. Areas are recorded as a series of x-y coordinates, defining line segments that enclose the area. These areas are referred to as polygons. With the x-y coordinate system polygons, lines and points can all be represented.

The ARC/INFO system was used as a model in the following discussion about terms, definitions and relationships of the operation of a GIS. It is one of many GIS systems commercially available. Terms used describing certain functions or features may be unique to the ARC/INFO system. Their functions however are common to GIS in general.

Maps use real world coordinates to reference points and these are projected onto a flat surface. The locations on the map represent real locations on the earth. These are then projected onto the flat map using one of several accepted map projections. Common projections include the Lambert Conic Conformal projection, the Albers Conic Equal Area projection or Universal Transverse Mercator (UTM). Longitude and latitude are also a geographic reference system but it is not a map projection, as it measures angles from the center of the earth rather than distances on the earths surface. Because longitude and latitude do not have a standard unit of length (one degree of longitude has a different length depending on the latitude) it is not a good system to use as a system of measuring distances over the earth's surface. The projection used on the map will have some distortion effects on the information displayed on it. Different projections will distort the features in different ways, making a particular projection useful in some situations but not useful in others. It is important to keep in mind one projection while building the base map. In the building of the base map information from all available area maps and drawings are converted to a digitized format either by the use of a map digitizer (a similar concept to a scanner) or by manually entering information into the database.

Once a map is digitized, the x-y coordinates are held in digitized measurements. In order to impose a scale factor on the measurements and also to make them meaningful, the coordinates must be converted to real world measurements, in the same projection as the original map. This process is called transformation.

Tic points (or real world locations) are used to provide a reference for each part of the map. Typically a table of tic points is developed before any of the digitizing takes place.

By recording all the tic point locations in the projected map coordinates, the transformation process then converts the existing digitized measurements into real world coordinates.

1.7 TOPOLOGY

A map allows a reader to interpret information from it that isn't explicitly pointed out such as tracing a route from one location to another or identifying two lots of land that are adjacent to one another. You do this by connecting points along the path or by defining enclosed areas with lines. In the digital maps these relationships are depicted using **topology**. A mathematical procedure for explicitly defining spatial relationships. This is the key ingredient of a GIS that separates it from a database alone or some other package of software. Topology is how the linkages are made between the geographic data and the descriptive data. Without the topology relationships, you don't have a GIS. For maps topology defines connections between features, identifies adjacent polygons and can define a feature such as a polygon as a set of other features like points or lines.

The ARC/INFO system uses three topological concepts to make the linkages of data. 1) Lines (or arcs) connect to each other at nodes. 2) Lines that connect to surround an area define a polygon. 3) All lines have a direction and a left and right side. Each arc has two nodes a from and to node. Lines can only connect at the endpoints or the nodes. These concepts allow the GIS to interpret the spatial relationships between features that a person would do by looking at a map and seeing how the features relate to one another. The computer can now tell which lines are connected and which lines aren't. A very useful tool to a public works engineer, especially if the connected lines represent a water line or

some property boundary. ARC/INFO stores polygons as a series of lines and these lines are defined as a particular polygon. Other systems do not use this convention and store polygons as a series of x-y points. In the ARC/INFO system a line may be a part of more than one polygon but the computer will store it only once. This helps to ensure that boundaries don't overlap. It also reduces the amount of data stored.

1.8 ORGANIZING MAP INFORMATION

Map features are logically organized into sets of layers or themes of information. These themes could be land use, streams, crops, trees, roads or a number of other useful features. Each theme or layer is referred to as a coverage which consists of topologically linked geographic features and the associated descriptive data (figure 1).

1.9 DESCRIPTIVE DATA

Descriptive data or attributes of features are stored in the computer in a similar manner to how coordinates are stored. The descriptive data is stored in a tabular way. One record stores all the information about a particular occurrence of a feature (e.g. a point arc or polygon). An item stores one type of information (an attribute) for all features in the database. These types of files are referred to as feature attribute tables.

1.10 CONNECTING FEATURES AND ATTRIBUTES

The real power of a GIS lies in its ability to link the graphic data with the descriptive data. This connection has three basic characteristics. 1) The one-to-one relationship between features on the map and records in the feature attribute table.
2) The link between the feature and the record is maintained through the unique identifier given to each feature (e.g. a polygon will have a number assigned as its identifier).
3) The unique identifier is physically stored in two places, in the files containing the x-y pairs of the feature geographically and with the corresponding record in the feature attribute table. This connection is automatically created and maintained by the system.

Connections between attribute tables are made by what is referred to as a relate. A relate is a temporary connection between two attribute tables that share a common item. A relate therefore has the effect of making an attribute table wider by temporarily adding feature attributes which aren't actually stored in the attribute table. A relational join is another function of the GIS and is a way to combine descriptive data. A relational join relates and merges two attribute tables using their common item.

CHAPTER 2

PUBLIC WORKS APPLICATIONS OF GIS

2.1 Introduction

The number of applications of GIS to public works is numerous. They cannot all be detailed here. Some successful applications of GIS in the public works realm will be described

In general the GIS can help the public works engineer manage the large amount of information that any public works organization has available. Too often this information is scattered throughout the organization in separate file drawers in separate buildings and in many formats and filing systems. Most of the geographic information needed to carry out the day to day business of the office is on paper maps of all different sizes and levels of detail. Pulling together the information needed for the public works engineer can be as difficult and as time consuming as the problem he is attempting to solve with all the information. A GIS system properly designed and implemented could eliminate countless wasted hours of searching for, and collecting data the engineer needs to do his job. Additionally the GIS can give the engineer new information by combining different data sets that were not there previously. This would allow the engineer to make more informed, more timely decisions about the facilities in his area of responsibility. The examples that follow will show some specific applications of GIS in the public works sector.

2.2 GIS INFRASTRUCTURE MANAGEMENT

Because public works managers must face the task of increasing public service while dealing with ever shrinking budgets, and at the same time the infrastructure they manage becomes older and fails at a growing rate. One way to help improve this situation is through better information management.

One way of doing this is to give field crews up to date and descriptive maps to work off of and giving managers historical records of previous maintenance.

Computerized infrastructure management tools have been used for several years by many municipal and county agencies. Software available to engineers to do modeling include, CAD and drafting and maintenance and field inspection applications. Most software packages focus on one part of an organization such as drafting software for the engineering department or a database application designed to track maintenance. Advances in computer hardware and software now make it possible to integrate all levels of data and allow that data to be shared by all departments.

GIS based Computer Aided Software Engineering (CASE) will allow more data to be shared more rapidly by all departments in an organization. In order to do this agencies will have to develop strategic plans to merge their computer applications into a common structure. City and county wide systems will need to be used by all departments. This type of approach allows for a common user interface for all users, establishes agency wide data and reporting standards, allows for the most efficient data sharing capabilities, eliminates duplicate data entry and provides ready data access to better respond to service requests and emergency situations.

The uses of expert systems in the field of public works management has been increasing rapidly (3). Expert systems use a set of user defined rules to support intelligent decision making. In regards to public works management this could be used to combine historical data with some modeling data to meet maintenance and production goals. Some areas that will benefit from this type of data combining are maintenance departments who could use the model to budget for predictive maintenance costs or to those involved in recovering from catastrophic events and disaster recovery operations.

A GIS system will allow public works departments to put all their data and expert systems information together by tying the data with geographic coverages. Analyzing a variety of coverages could result in determining the useful life remaining in a building, expected frequency of an event or the cost effectiveness of different rehabilitation projects.

Engineering repair and maintenance models are being developed to utilize information from a variety of sources such as historical maintenance activities, field inspection data, as built drawings, construction standards, capacity/demand models and other information gathered and recorded through routine maintenance. Links to geographic data bases can be combined from sources outside the organization such as the U.S. Census Bureau's Topologically Integrated Geographic Encoding and Referencing (TIGER) reports or USGS reports. Models are being established to develop a rating factor to evaluate the severity of one maintenance factor to another. Such as root intrusion, pipe depositioning, pipe deterioration and waterline breakage models.

Once rating factors have been established, managers can make decisions on how to plan maintenance or replacement projects. This is a dramatic difference between the typical management tool that will simply schedule maintenance based on a user defined interval. By combining all geographic, and engineering and maintenance data into one database, the information becomes critical feedback for maintenance scheduling.

An example of the combining the data in this way might be a waterline breakage model. The model would have access to data concerning pipe material, size, and depth from maintenance records then use soil and other ground coverages from the geographic data. By combining the different sets of data the system could then display ares of section of pipe that were due for maintenance or all the areas where breakages are most likely. This becomes a very useful tool to the public works manager in order to get the most effective use of his repair budget.

2.3 A GIS Based Sewer System Evaluation Survey (SSES)

This system which was developed by the RJN group in Dallas Texas is a proposed system and to date is not currently being implemented by any municipality. It is included here to show its potential in this area (4).

GIS systems can be used to analyze waste water collection systems in an attempt to avoid sewer system overflows. A significant problem to all wastewater collection systems is the infiltration of ground water and the inflow of runoff into the system after and during a storm. Historically, hydrographs have been used for the graphical representation of the behavior of a waste water system. A typical hydrograph will plot the flow of water along the y-axis and time along the x-axis. Although the hydrograph is widely used it has several flaws. Low rates of flow from defects in the pipe tend to flatten out the peaks in the hydrograph. Point sources with high rates of flow, or sources close to the metering location cause peaks in the hydrograph. The traditional approach to analyzing the data on the hydrograph did not allow for the variations in rainfall over the area being studied. It also did not take into account the time it took for water to travel from different points of the study area to the outlet. A GIS could be put into this scenario after some equipment is installed to do a much more thorough analysis on the inflows and infiltrations in order to detect defects in the system. A GIS system could accurately measure and analyze rainfall and flow patterns more accurately. Rainfall intensity gauges would be placed in certain parts of the study area and flow meters are placed at the outlets of the basins that will record the actual rainfall data. Field reconnaissance is also done to record rainfall locations and to trace water flows. When all the data is collected the GIS can run an analysis and determine optimal repair replacement strategies for the system. It can then take that information and overlay it onto a data layer carrying information on land ownership and determine how much of the pipe lies on public or on private property. The GIS will also allow the engineer to run some modeling algorithms to determine what effect repairs at one

point in the system would have on other points in the system. This will allow the government agency to maximize repairs while minimizing the cost. The GIS will also give the engineer the opportunity to run modeling algorithms concerning the effects of major construction in the area, giving him a better planning tool.

2.4 SANTA CLARA COUNTY TRAFFIC NOISE STUDY

In Santa Clara County California, a GIS was used in the study of noise impact of a proposed highway project (5). The current system of analyzing an area for sound data took many hours of hand putting thousands of x-y coordinates into the computer. The shear number of points to be inputted lead to many possibilities of errors being introduced.

The GIS could quickly digitize and store all the x-y coordinates error free in one coverage layer. Each lane of the highway was then defined by a number of line segments, digitized and stored in another separate coverage. Sequentially, natural sound barriers and constructed sound walls were digitized and stored each in its own coverage. With the help of an editor and some sound analysis software, different noise levels at different barrier configurations could be studied.

Using the GIS dramatically reduced the time spent entering data and correcting errors introduced and also improved the accuracy of the study

2.5 NORFOLK, VA STORM WATER MANAGEMENT AND GIS

Norfolk VA used their GIS to study its needs for storm water management information (6). Norfolk's Public Works Department is responsible for 32,000 manholes, catch basins detention areas and other structures that remove excess storm water and reduce the risk and impact of flooding. Making decisions concerning regulatory

requirements, capitol improvements, maintenance and responses to citizens was a time consuming and cumbersome task. The PWD decided to look into implementing a GIS that would help them make those kinds of decisions faster and more accurately.

During the study and design of the system the city staff identified specific information needs the new system would have to handle. The items arrived at were divided into two categories, Planning needs and Engineering needs. The new system would have to handle public inquires and complaints, site development, hydrology for flood mitigation, operations and maintenance, capitol improvements, planning, water quality management, and regulatory information support.

The city had several goals at the start of the design process.

1. Maximize the use of existing city databases
2. Maximize sharing of data.
3. Minimize data updating and maintenance
4. Minimize the amount of data conversion
5. Maximize the sharing of data among city departments and maximize the use of existing hardware

figure 3 shows the different layers of information proposed for the system. This system will allow Norfolk PWD to build an accurate database of the different aspects that go into a comprehensive storm water management program. With this system all departments in the city can use the data to make wise engineering and planning decisions, in a timely and cost effective manner.

2.6 TRANSPORTATION

Many applications of GIS technology have been used in the field of transportation throughout the U.S. and Canada. The next two examples are from the field of transportation.

2.7 VANCOUVER ISLAND HIGHWAY PROJECT

This project was a major road construction project involving 127 Km of 4 lane limited access highway, 30 Km of other roads, 37 major stream crossings, 10 interchanges and 20 other grade structures (7). The project was to pass through some environmentally delicate terrain in a part of British Columbia that is very aware and concerned about the environment. The British Columbian government required the contractor to utilize a GIS in the design process to address the environmental issues.

The contractor had to develop a system to incorporate data from aerial photography, topographical field surveys, impact field surveys, data from highway design information and owner notification data.

The contractor developed a system based on the ARC/INFO GIS software package by Environmental Systems Research Institute Inc. (ESRI).

After Global Positioning System (GPS), aerial photography, field data and owner data were collected the data were put into the GIS. From there the contractor could generate high quality maps for use by different environmental agencies to identify environmental problems. The GIS was able to help the contractor make the most desirable route considering all factors. It was determined for the expense of the system to be justified, that the system should be maintained throughout the life of the highway. This would allow for the data collected and base maps generated to be used for monitoring maintenance, noise impacts, accident history and avalanche history.

2.8 GIS IN A PAVEMENT MANAGEMENT SYSTEM

Pavement management is one infrastructure management application which combines GIS with expert logic for managing street and highway projects.

According to the American Association of State Highway and Transportation Officials (ASHTO), pavement management is the effective and efficient directing of the various activities involved in providing and maintaining pavements in a condition acceptable to the traveling public (1). AASHTO also defines Pavement Management Systems (PMS) as the established, documented procedure for collecting, storing, processing and retrieving the information required in a PMS.

There are four basic components of infrastructure management: inventory, condition, evaluation and implementation. In the development of the GIS based Pavement Management System the first component to be considered is the inventory of the highway system itself. The first option to be considered here is the accuracy of the base maps that are to be developed and level of accuracy in the output maps desired. A great deal of time and expense are required to create and produce maps with a high degree of accuracy. A more efficient approach to creating high detailed maps is to keep a highly accurate database (which doesn't cost any more to input or store) and having the generated maps from the system use a lessor level of detail. This results in a system that has enough detail in the database to do engineering calculations without the high cost of having maps produced with a lower priority super high quality.

The second option to consider is the structure of the database. The developers of the GIS may find it to be cost effective to start a GIS with one level of accuracy and then improve the accuracy at some later date. The U.S. Census Bureau's TIGER (Topologically Integrated Geographic Encoding and Referencing) files are a good economic source of data on road systems. TIGER was created in 1990 for storing and retrieving Census data, it was designed to provide a topological database for every street

and block face in the country. It provides enough detail of the highway system to be adequate for pavement management, transportation planning and traffic engineering. It falls short of providing enough detail to make engineering quality prints from its database

Examples of some of the data fields needed to have an effective PMS include road width, curbing, parking, traffic counts, number of lanes, right of way width, shoulder type, speed limits, one way traffic indication, pavement layers history and repair history.

The next component of infrastructure management to consider when building the GIS is the assessment of condition. In pavement management throughout the country there are about 18 different distresses that can be tracked that describe pavement condition. In order to be more meaningful for comparison these distresses are further broken down into severity (how much the distress has progressed) and the extent of the distress (how much of the road surface is effected by the distress). Severities are normally measured as a low medium or high (based on depth or width of cracks or other distress) while extents are generally measured in lineal feet of pavement.

Using all these parameters for an entire roadway system can quickly add up to a database that is to large to maintain adequately and too costly to develop. In this model the focus was put on different repair strategies commonly used and tracing the strategy backwards to the distress that caused the need for it in the first place. To further streamline the database the distresses that are too difficult to identify can also be eliminated. The final model for the PMS includes only five distresses: Alligator cracking, transverse and longitudinal cracking, potholes, patching and edge deterioration.

With this database in place the GIS can then recommend repair strategies based on the type of distress, severity and extent.

The next step in the process of developing the system consists of combining the recommended repairs with the inventory data. The software then combines quantities with unit repair costs. A priority is then assigned to the repairs based on the defect rating of a piece of highway, the road class and traffic volumes.

As maintenance and repair work are completed, the work completed can be added to track progress and develop the roadway maintenance history.

Although a GIS is not necessary to have an effective PMS, benefits from a GIS based system over one that is not include:

Display and interpret data using maps of any agencies road system

-Street section displaying a specific type of distress or severity level

-Street sections requiring a specific repair activity

-Planned and completed maintenance

Perform spatial queries

-How much money can be spent in various districts

-How are maintenance activities geographically distributed

Other benefits of a GIS resulting from data integration.

More and better information for the road system manager

Better coordination between departments

Ability to add more data layers to the same base map

GIS also provides capabilities to run network algorithms which could be used to optimize waste collection routes, oversize truck routes and emergency management services.

2.9 GIS AND NEW YORK CITY INFRASTRUCTURE

Another application of GIS and public works began in the mid 1980's when the City of New York began to develop a computer assisted mapping technique for the sewer system. There are over 6,000 miles of water main with the associated attribute data located throughout the 5 boroughs of New York City. The project was initiated to update all the records and develop a database for planning, design and operations/maintenance activities.

The problems New York was having with information in database and map form is typical of many public works organizations. File information is incomplete and not all that

easy to access. Maps drawings and other utility related documents were of different sizes, scales and detail, as well as being outdated and inaccurate.

New York has an immense task with its 350 square miles across the 5 boroughs. Keeping track of sewer lines, water mains, electric, telephone and TV cable systems, steam, and gas lines. Their task is complicated further by the age of some of the systems, over 100 years old in some cases. The shear number of miles (over 20,000 line miles), constant renovation, multiple management agencies and reconstruction make it almost an impossible task to efficiently manage.

The project to update the city's system began in 1983 when the city Department of Environmental Protection (DEP) awarded a contract to URS consultants to develop a GIS master mapping plan for the northern half of the Borough of Queens. Last year the project expanded to complete the over 31 million feet of water mains throughout the entire city. The initial database consisted of over 6,000 maps of various scales, level of detail and degree of accuracy. Because the existing data on the city wide water main system was incomplete an additional 700 maps were required to do the job.

To take on a project of this size the contractor and the city had to get together to derive a start up system to begin to implement the GIS system. Figure 4 is a recommended start up procedure used by the city and contractor. It should be considered when taking up a GIS project. There are actions a city should consider when recommending GIS based projects:

1. Establish an in house technical review/advisory board to represent a cross section of departments and employees to:
    - A. To establish specific applications, goals and objectives
    - B. Consider the needs of outside resources
    - C. Develop a scope of work, budget and milestones
    - D. Prepare if needed a request for proposal
2. Determine the initial design/architecture of the system and its resulting output

3. Gather user inputs through interviews and first hand evaluation of all prototypes and first products.

After the decision was made to go to a GIS system another decision had to be made about which system to go to. There are more and more systems to choose from every day. The criteria for the choice included: hardware, software, database size, cost, and personnel. The most important factors were the current database and its proposed use. Some tough questions had to be answered before choosing the system. A database structure needed to be agreed on as well as the applications for manipulating the data and the level of user interface.

The city's initial decision was to go with a system that only mapped out the sewer infrastructure. Early in the study they realized the benefits of having multiple infrastructures included in the system. The decision was made to incorporate the water and steam infrastructure as well in the system.

One of the first steps taken in developing the system was to standardize the mapping system. The current mapping system consisted of many different maps with different scales and different symbols and linestyles. Selecting a single standard was effected by legibility at the required scale, conflicting standards at the source of information, hardware and software limitations and most importantly the potential use of the final product.

Existing maps had to be digitized to become part of the GIS. Specific engineering techniques as well as cartographic rules were established to make detail scale changes, edge matching requirements and changes from schematic to actual layout. The use of the final product had its influence on the rules used to match the maps together.

Determining the required information and its availability and reliability was a top priority during the initial setup of the project. Most of the source documents used had to be copied on site because they could not be removed from the office where they were.

The next step to be considered after collecting all the pieces was to digitally translate all the maps to a usable format and then consolidate the data into a standard production unit.

It was discovered early in the project that making the base map would be difficult. The cost to create a high quality base map from scratch to the level of detail required was prohibitive. What was needed was to use all available materials such as aerial photography, as built drawings and related planning documents to make the seamless base map at a reasonable cost. A large problem occurred when trying to edge match all the pieces together keeping a close eye on the possibilities of the propagation of errors. Converting all the maps digitally presented some labor problems. Doing all the digitizing by hand placed an overload on the CAD operators. A better faster solution was to digitally scan all the data in. The scanner creates a matrix of black dots that it stores wit an x-y coordinate for each dot. These types of files called raster files became large very quickly. What was needed next was to convert the raster files into vector files. The vector file connects adjacent dots into a line. The resulting vector type file holds only the coordinates of the end points of the lines. This type of file was much easier to handle and edit.

Once all the pieces were digitized they had to be put together. In most cases the edges of the maps did not match up. To eliminate the kinks that resulted an automated system was imposed on the drawings to match the edges. This ended up being the most labor intensive part of the process. The people responsible for putting together this system realized that to have a successful product they had to keep in mind that the "S" in GIS stands for system and is more than just hardware or software. Database design, organizational structure, personnel, time, finances and management support are all very important parts of the system.

CHAPTER THREE
BUILDING A GIS

3.1 Introduction

Till this point the discussion on GIS has focussed on the basics of a GIS system and how it can be applied to public works projects. This next section will focus on how to conceive, build and manage a GIS in a public works setting.

3.2 Design Procedures

Many organizations have purchased and built GIS systems in order to improve the organization. Some of the benefits these organizations were trying to realize include doing more with fewer resources and deriving greater benefits from staff activities. For example making corporate information available to all. Specifically in a public works setting the expected benefits of implementation of a GIS include lower administrative costs leaving more tax dollars to complete more projects and better service to the public.

These are very noble expectations from the implementation of a new computer system. It is also widely accepted that the purchase of an expensive GIS system does not guarantee these benefits. (9)

In trying to tie a GIS to an organizations needs and goals, a somewhat different definition of a GIS is given at this point. It is defined here as; "The application of information, technology, data management principles and organizational theory to the geographical needs of the organization" (9).

William E. Huxhold and Allan G. Levisohn have done extensive research in the field of building and managing a GIS. In their book "Managing Geographic Information System Projects" they outline the necessary steps and elements involved in building a GIS for a specific use. The following discussion will, in brief, outline their process for building and managing a GIS.

Key to the whole system is what they describe as the GIS Paradigm. They define it as follows: "A conceptual foundation for using geographic information that provides a common base of reference or focus for the other three elements needed to successfully implement a GIS. The other three elements are: 1) Database management principles. 2) Technology and 3) Organizational setting.

In the first section of this paper a definition for a GIS was given and how it was different from other computer systems. There the factor that set GIS apart from the others was its ability to link descriptive data and geographic references. This, in short, is the meaning of the GIS paradigm. There are three concepts involved in this linking element of a GIS. They are:

1. Georeferencing - The process of locating features within a model of the surface of the earth.
2. Geocoding - The process of attaching a geographic reference to non geographic data.
3. Topology - The branch of mathematics which defines the relationships between features.

These concepts put together can create a model of the real world that will allow the user to extract information useful in making decisions.

In order to implement this idea you must first build a model of the real world based on your interpretation of it. That interpretation is different for different organizations. Depending on where you are and what your organization's purposes are, different parts of the real world are more important than others and the model you create would be different from another organization's.

The organizations perception must then be made into an organized data model. This consists of two kinds of data, the geographic or spatial data and the descriptive information. When put together the data model describes the following physical features;

how the data are used, who uses them, the processes involved in managing them and how the data are moved about (figure 2).

To be incorporated into an entire organization it is important for the system to be used by all the organization. This puts the requirement on the system to be able to use different databases from different departments within the organization. It is necessary to establish a common data platform for which all the users of the system can input their individual data.

Once the common standards and conventions are established, a method for managing the data, inputting it and keeping it current needs to be established. This strategy effects the entire organization because it effects the allocation of funds for the staff, for the data collection and input equipment.

The next element in the building of a GIS is the technology. The advances in computer technology have made the implementation of GIS practical. The selection of the technology used in a system is an important one. A careful analysis of what the organization's goals and needs are will help in the matching the best suited technology to the data and organizational needs.

A GIS incorporates many different technologies for storing, collecting and reporting information. Computer assisted mapping, database management software, digital instruments to collect geographic coordinates as well as word processing capabilities are all technologies that may be needed for a system depending on organizational needs. A table showing some technologies and there applicability to a GIS system are shown on table 1.

In order for an organization to realize the full benefits of GIS it must be incorporated into the entire organization. The system is more than just another software package to be used at individual computers. How the systems fits into the structure of the organization is important. Organizations are structured to meet their individual missions. The GIS needs to be set up in a manner to support that mission.

Each GIS is unique. There are over 60 million commercial computer products on the market. Each having its own characteristics. Building a GIS is a matter of constructing a graphic and non graphic database, developing or obtaining information processing capabilities, installing the appropriate computer hardware and software and then implementing the organizational procedures and staffing changes needed to operate and maintain the system efficiently. Choosing a system based on price or buying a system that is supposed to be the best will not deliver effective results. Without a clear definition of how each user is expected to use the system it will be difficult to build databases, select commercial products and then use the system. Knowing how the system will be used forms the basis for determining what and how the data is stored and retrieved. The process of doing this is referred to as system design and is a key step in building a system.

The system design process considers the needs of all the end users of the system and tries to answer the following questions:

1. What maps must be produced?
2. What data must be available from the system?
3. How are the maps and data to be processed?
4. Who will update what data?
5. How will updates be disseminated to users?
6. What hardware and software will be needed?
7. Who needs what type of equipment?
8. What technical staff is needed to support the system?
9. Who needs to be trained and what training is needed?

These and other questions that occur during this phase of the building process can be separated into 9 categories:

1. Functions
2. Data
3. Applications

4. Hardware and software
5. Staffing
6. Training
7. Procedures
8. Organization and institutional changes
9. Legal considerations

Addressing the needs in any one of these categories helps the design team answer the questions in the categories below it on the list. This creates a hierarchy of needs for the system (Figure 5).

It takes addressing all of these issues in order to have any real chance the system will be effective and actually improve performance of an organization. That is why the organizational changes are at the end of the network. A determination has to be made as to which maps to update and what computer hardware to use. Once that is done organizational policies and procedures need to be modified to ensure that the system works as a whole throughout the organization.

Determining what data are to go into the system is more involved than simply polling all end users to see what their needs and wants are and then putting that into the database. Because the cost of digitizing data far out weighs any other single component (50%-80% of the total cost) it is important to verify that each data item entered into the computer is essential.

A good way to determine the data needs is to survey all the functional units of the organization and determine what data is currently being used. This approach has two benefits. One, it ensures all departments are covered in the development and two, it allows the design team to know what data they can expect will be used on a continuous basis. There is a drawback to this type of survey. It only addresses what data are currently in use. It does not take into account other data that might be used if it were available. In designing the system the designers will want to stay clear of automating an inefficient or ineffective

process. In that light the survey of current data uses must also include room for the users to make comments on the use of that data pertaining to problems or inefficiencies with its use. A similar survey should be done concerning the use of maps in each functional area.

Once these surveys are done the design team has an overwhelming amount of information about the map needs and data use. Because of the cost of adding information to the database all the needs and wants cannot be included. A method of determining the importance of the results is to put all the information into a matrix. The matrix then displays the relationship between map users on one axis and all the maps used on the other. The cells where the rows and columns intersect give a determination of the importance of that map. Figure 6 shows an example of what one such matrix might look like in a public works organization. Armed with this information the design team can assign some priorities on what to include in the database.

After the design team has a good feel for the data needed it then needs to be determined what applications will be incorporated into the system. This phase is not as difficult as the first stage. Once the data to be used is determined each functional area will only have certain uses for that data. The different units generally have specific outputs it produces with the data. Determining the applications to use can then be done by asking each unit three questions.

1. What data are processed? (inputs)
2. How are the data used? (applications)
3. What is done with the data after they have been processed? (outputs)

The needs surveys that were already completed have all the basic information necessary to define the needed applications. What is needed now is to add some structure to the analysis. This is done by interviewing those doing the procedures and reviewing written policies. In order to keep track of all the design applications it is helpful to use a standard format that indicates all the specifications of the applications. This could be a form

identifying the function being performed, the data input requirements, processing requirements and out put products.

Having accomplished this the design team can begin to develop a scope of the system. Because of the number of different applications that can arise in the previous phase, the design team needs to prioritize the applications. A priority is important because the implementation could take months or years to accomplish. The design team will want to get the most important applications on line first.

Once the functions to be incorporated are chosen, data to be include determined and the applications to include in the system are known, it is possible to start specifying the hardware and software requirements.

In general GIS software can be grouped into three functional areas

- Automated mapping functions: These functions manipulate the cartographic records of the GIS. They are used for extracting, updating, creating and producing high quality maps and drawings.
- Data management functions: These functions manipulate the non geographic data stored in the GIS. They create and update, retrieve and manipulate selected records and produce standard and specialized reports.
- Spatial analysis functions: These functions use both cartographic data and attribute data. They produce results of a statistical nature and often create new maps or new databases.

Determining the hardware required of a GIS is made easier by working backwards from the input and output needs of the applications for each user. The specific hardware components to be considered are:

Workstations

Plotters

Digitizers

Printers

Scanners

Alphanumeric keyboards

Work stations There are basically two options available for workstations. One, a terminal connected to a central computer that may have additional terminals connected to it. Two, an intelligent workstation that is itself a computer and can be connected to other intelligent workstations via a communications network. A centralized system has all the software and data files at one central computer. All the terminals use the same software and data files.

A network system allows a more versatile use of software, hardware and data files. Each computer in the network can operate independently of the other computers with its own software and hardware devices. Additionally each computer can also have access to the data files, software and hardware devices of the other computers. The choice depends on how versatile the system needs to be in order to meet the needs of the users.

Plotters There are two basic choices to be made for plotters as well. The electrostatic type or pen plotters. The choice will depend on the needs of the particular use. The pen plotters deliver a high quality product but are more expensive, require more maintenance and are a great deal slower than the electrostatic versions.

Digitizers These are needed in only a limited capacity in certain situations. In the building of the base map it may be necessary to use the large digitizing tables, while after the system is on line and only updates are necessary a smaller less expensive digitizing tablet may be used.

CHAPTER FOUR
CONCLUSIONS

There were three main objectives to this report. The first was to introduce the person not familiar to GIS to the terms and structure of a system. Chapter one discussed these topics. The second objective was to show how these powerful systems could be applied to real life public works applications. In Chapter two several cases were discussed where GIS systems had been set up or outlined for future implementation. The third chapter of this paper addressed the third objective of showing the person unfamiliar with GIS the degree of effort required to successfully implement a system. After all the hardware, software, data and functions have been determined the system can begin to be implemented. Putting a sophisticated GIS together, building a base map, database, loading and configuring software, connecting hardware and putting into place new procedures is a huge undertaking for any organization. The success of the final system and weather it helps the organization or not falls largely with the commitment the organization has put into it. If there is a lack of support from one of the areas used to build the model, the chances of success are low. The most important source of the support must come from the top management. If the management is not behind the project from the start then people down the chain of command will not get on board with the program and it will fail.

Although there are many useful applications of GIS being incorporated in the field of public works, and many more interesting applications yet to be introduced. It is important to remember that GIS is a tool. Like any tool it should be used to make your job easier. If a GIS will not help you do your job more efficiently, or with better service, than it isn't helping you and its not a good tool for you.

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FIGURES AND TABLES

Different Data Layers over an Area

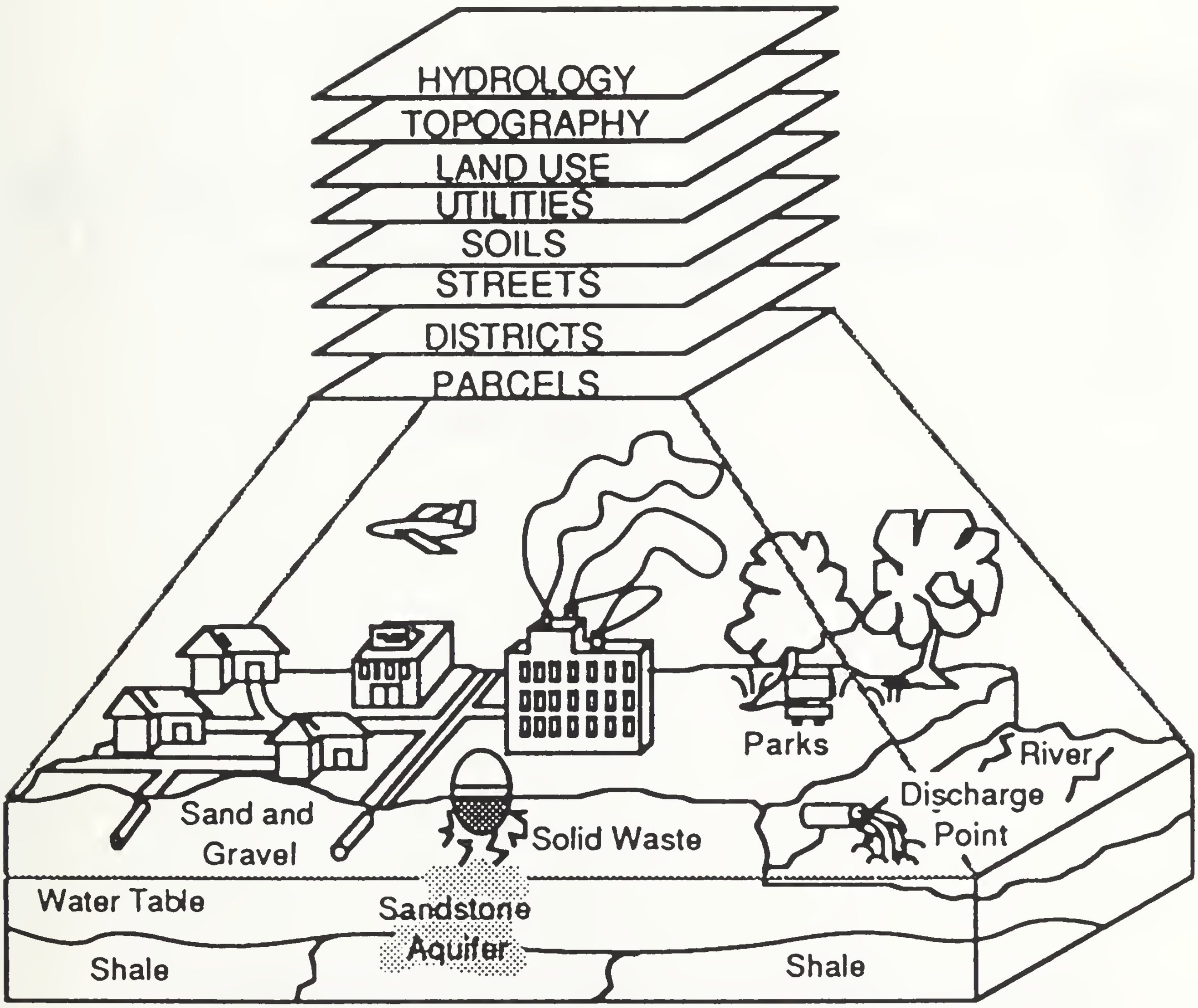

FIGURE 1 From Understanding GIS The ARC/INFO Method

Several Components comprise a GIS

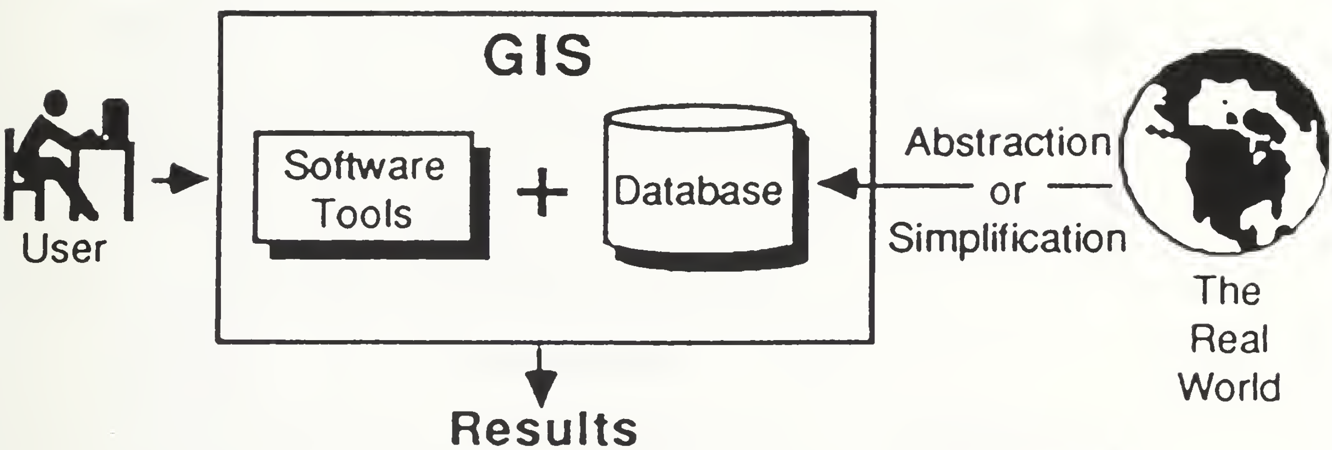

FIGURE 2 From Understanding GIS the ARC/INFO Method

Proposed Graphic Layers

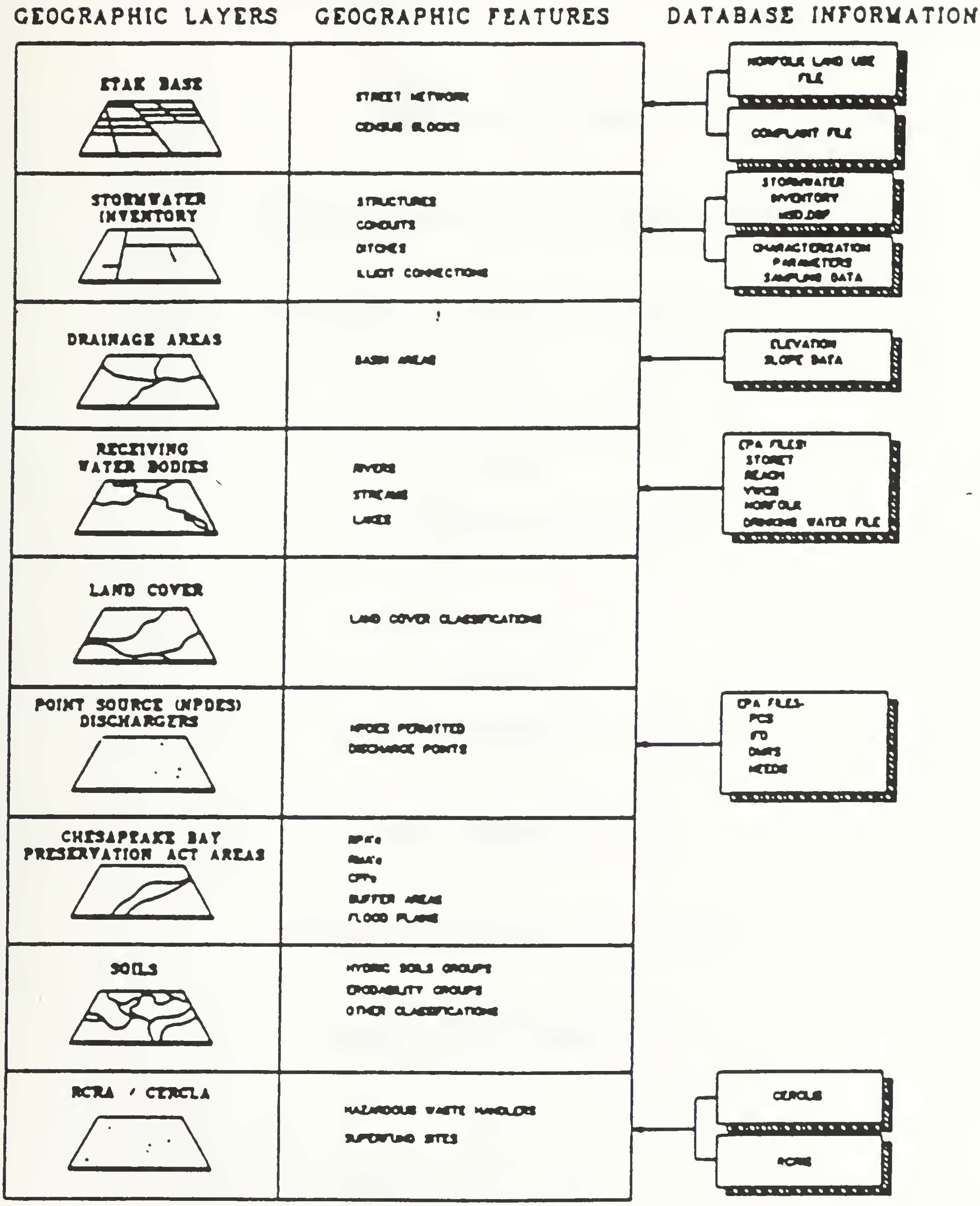

FIGURE 3 From (6)

Initialization Procedures For GIS Based Projects

DETERMINE NEED

ESTABLISH GOALS AND OBJECTIVES

DEFINE SCOPE OF WORK

PLAN ORGANIZATION
AND
PRODUCTION CONTROLS

ACQUIRE SYSTEM
AND/OR
SELECT CONSULTANT

INITIATE PILOT STUDY

ENHANCE REFINE AND REVISE

IMPLEMENT PROJECT

FIGURE 4 From (8)

GIS Hierarchy of Needs

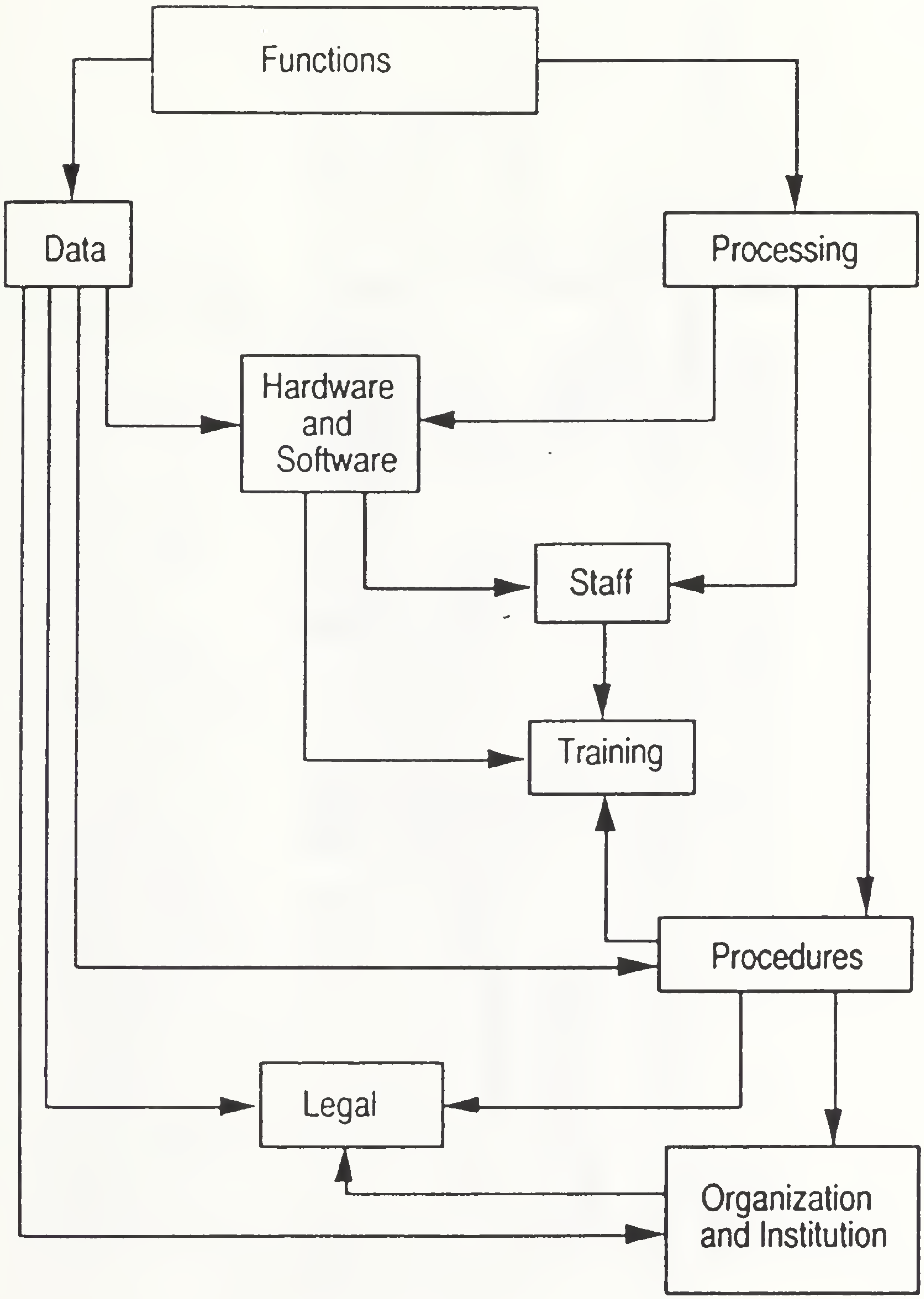

FIGURE 5 From (9)

Geographic Information Needs Matrix

	City Engineer	Planning Department	Building Inspector	Tax Assessor	Traffic Engineering	Election Commission	Cable TV Administration	Health	Mayor's Office	Community Development	Fire	Police	Sanitation	Water Works	Forestry	Common Council	Street and Sewer Maintenance	Municipal Equipment Management	Outside Agencies	Public Information
Quarter Section Mapping	■	■	■	■	■		■	□	◧	□	◧	◧	◧	■	◧	◧	■		■	◧
Construction/Paving Plans	■		■		■									■			■			
Curb Lines	■	■	◧	◧	■		■					□		■	□		■		■	◧
House Number Atlas	■	■	■	■	■		■	■			■	■	■	■	■	□	■		■	□
Land Use Maps		■	■	■	◧		◧	□	□		◧	◧	□	□	□	□	□		■	□
Choropleth Maps		■	◧	◧	◧	□	◧	◧	◧	◧	◧	◧	◧	□	□	◧	◧		◧	◧
Zoning		■	■	■					□							◧			◧	◧
Plan Examination			■	□												□				□
Inspection Workload			■													□				
Violation Mapping		◧	■				◧	◧	□	□						□				□
Redistricting			■				□	□								□				
Tax Plat Mapping	■	■	■	■	■		■	□	□		□	□	□	■	■	◧	■		■	◧
Street Light System			□		■		◧							□		□	□		◧	□
Underground Conduit			□		■		□							□		□	□		◧	□
Traffic Signal Records			□		■		□					□		□		□	□		◧	□
Traffic Control Maps			□		■		□					□		□		□	□		◧	□
Accident Data		◧			■				□			◧				□			□	□
Election District Maps	◧	◧	◧	◧	◧	■	◧	◧	■	◧	◧	◧	◧	◧	◧	■	◧	◧	◧	◧
Reapportionment	◧	◧	◧			■			■							■				□
Cable TV Monitoring			◧		◧		■		◧					◧		■	◧		■	□
Violation Inspections		◧	■				■		◧							■				□
Inspection Management								■								□				□
Violation Mapping		■	■					■	□			□	□			□				□
Arson Investigation									◧		■	■				◧				
Incident Maps									◧		■	■				◧				
Resource Allocation/Fire									◧		■	■				◧				
Crime Statistics									◧		◧	■				◧				□
Resource Allocation/Police									◧			■				◧				
Automated Dispatch												■								
Garbage Collection								◧					■			◧		■	◧	□
Snow Removal									◧		◧	◧	■			◧		■	◧	□
Off Street Parking		◧											■			◧		■	◧	□

Key: ■ Used Continually ◧ Used Frequently □ Used

FIGURE 6 From (9)

Candidate Information Technology for GIS Implementation

Technology	GIS Application
CAD (computer assisted drafting)	Digital mapping
DBMS (database management system)	Manage and retrieve land-related records
Geoprocessing (spatial analysis) using	Various land and resource analysis models such operators as overlay, proximity
Remote sensing and image analysis	Display and analysis of geographic images linked with other geographic data
GPS (global positioning system)	On-site collection of geographic coordinates
Multimedia (e.g., sound, video)	Video image of pavement condition referenced to road segments
SCADA (supervisory control and data acquisition)	Water or gas valve control from geographic database of valve locations
Document imaging	Store and retrieve card images of maintenance records; store images of building floors
Text processing	Automatically generate letters of notification to property owners determined from a spatial query
Network communications and electronic data interchange (EDI)	Link databases and users in different locations such as separate parts of an organization or different organizations

TABLE 1 From (9)